D4

(*Reprinted from Nature, Vol.* 234, *No.* 5326, *pp.* 210–211, *November* 26, 1971)

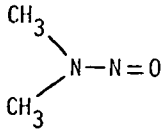
Organic Analyses of Selected Areas of Surveyor III recovered on the Apollo 12 Mission

THE Apollo 12 astronauts recovered the television camera, the trenching scoop and a few smaller items from Surveyor III, which had been on the Moon for 31 months[1]. They noticed that the white surfaces of the spacecraft had become tan. The television camera remained in the Lunar Receiving Laboratory (LRL) during the quarantine period and afterwards preliminary microscopic visual examinations and extensive photography were conducted at the LRL. The camera was then shipped to Hughes Aircraft Company for detailed studies and disassembly. Whenever possible the camera was handled and examined in laminar flow clean areas. On close examination, optical interference patterns were found on the camera mirror. The effects of lunar particles on this mirror had been observed earlier[2]. We report here the organic contamination of the mirror surface and camera exterior (shroud) attributable to the spacecraft outgassing, Lunar Module (LM) descent engine blasting, possible Surveyor III engine exhaust products —although thought to be unlikely due to the spatial configuration of the spacecraft components—and unknown sources. A more detailed report of these data will be published by NASA[3].

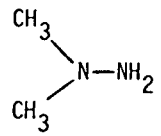
The camera mirror and middle shroud were extracted for organic material by washing the surface with benzene or benzene and methanol (3 : 1) squirted on by a syringe and collected in a beaker. The area of the mirror which was washed with benzene was approximately 35 cm^2. The whole operation was carried out in a class 100 organic clean room. These wash solvents (redistilled nanograde purity), as well as the sample washes, were concentrated on a rotary evaporator and the total residues subjected to high resolution mass spectrometry. The mass spectrometer system consisted of a modified GEC–AEI MS-902 high resolution mass spectrometer on-line to an XDS Sigma 7 computer[4–6].

The solvent background (less than 0.1 p.p.b.) consisted of hydrocarbons, chiefly the series C_nH_{2n-6} for $n=6$ to 16, and indications of carboxylic acid fragments, $C_nH_{2n-1}O_2$ for $n=3$ to 7, and phthalates (small peak of composition $C_8H_5O_3$). The residue from the mirror wash amounted to approximately 80 μg (about 2 μg/cm^2). It consisted principally of dioctyl phthalate, hydrocarbons of the series C_nH_{2n+2} for $n=3$ to 15,

C_nH_{2n} for $n=3$ to 14, C_nH_{2n-2} to C_nH_{2n-10} for $n=5$ to 12 approximately, carboxylic acids of the series $C_nH_{2n}O_2$ for $n=1$ to 16 and 18 (palmitic and stearic acids were the major homologues of the series) and in minor amounts silicones and LM engine exhaust products. The silicone oil was substantiated by ions of compositions C_3H_9Si, $C_5H_{15}OSi_2$ and $C_7H_{21}O_2Si_3$, derived from straight chain silicones and ions of compositions $C_4H_{13}O_3Si_3$ and $C_5H_{15}O_3Si_3$, derived from cyclic silicones. The peaks attributable to LM exhaust[7,8] are NH_3, HCN, fragments CH_3NH and CH_3NCH_3, NO, and $C_2H_6N_2O$ (I).



I

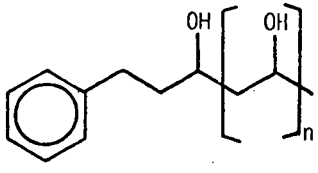


II

The nitric oxide is the major reduction product from the LM oxidizer, N_2O_4. The dimethyl oxazine (I) is a partial oxidation product of unsymmetrical dimethylhydrazine (II), the LM fuel.

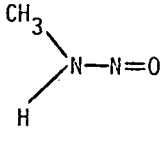
The middle shroud was washed with benzene and methanol on the side toward the LM and on the side away from the LM, and the extract residues amounted to approximately 120 μg (about 5 μg/cm^2) for the sample toward the LM and approximately 200 μg (about 8.5 μg/cm^2) for the sample leeward the LM. The major constituents found for both of these samples are hydrocarbons of the series C_nH_{2n+2} for $n=2$ to 29, C_nH_{2n} for $n=2$ to 19, C_nH_{2n-2} for $n=2$ to 16, with minor amounts of C_nH_{2n-4} to C_nH_{2n-10} for approximately $n=6$ to 13, dioctyl phthalate and silicone oil. This was substantiated by the same peaks in the high resolution mass spectral data as for the mirror sample. The minor components of these samples are nitrogenous and oxygenated compounds. A group of oxygenated peaks indicate a partially depolymerized vinyl alcohol–styrene copolymer (III)[8]. The peaks of compositions $C_{13}H_{19}O_3$, $C_{11}H_{15}O_2$, $C_9H_{11}O$, and C_7H_7 (tropylium ion) fit the pyrolytic fragmentation pattern for the copolymer III. The LM descent engine products are more varied in these samples than in those from the mirror wash, but still minor. Ions fitting the compositions NH_3, HCN, probably acetonitrile and propionitrile[7,8], NO, CH_2NO, CH_3NO, C_2H_5NO (N-hydroxyaziridine[8]) and the fragment series $C_nH_{2n}NO$ for $n=3$ to 5 and $C_nH_{2n-2}NO$ for $n=5$ and 6 are found. The peaks of composition $C_2H_6N_2O$ (I), CH_4N_2O (IV), and CH_5N_2O (a protonated species of IV) are present in significant amounts. The methyl oxazine (IV) may possibly be derived from the Surveyor III engine

exhaust, because the fuel used was mainly monomethylhydrazine (V).

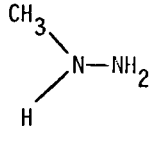


III

In summary, essentially the whole outside surface of the Surveyor III television camera was covered by lunar fines, probably from the following sources: Surveyor landing, lunar transport due to meteoroidal impacts, LM landing, and



IV



V

redistribution during return and subsequent handling. Thus the evidence for LM and possibly Surveyor III descent engine exhaust products on the shroud and mirror is not surprising. The side toward the LM was heavily sandblasted and more discoloured than the side opposite. This fact was not too well demonstrated by the organic material isolated from the shroud, except that the total ion current for the leeward sample was about double that of the sample from the side facing the LM. The same types of organic molecules were found on the mirror and both shroud samples. The sources of the various organic contaminants[9] are as follows: hydrocarbons from lubricating oils; general terrestrial contamination from exposure and bagging material; dioctyl phthalate from polyethylene bagging material (the plasticizer); carboxylic acids from decomposition of grease and general terrestrial contamination and handling; silicones from sources as lubricating oil, outgassing of electronics and plasticizer; styrene–vinyl alcohol copolymer probably from electronics insulation; and nitrogenous compounds from LM and possibly Surveyor III engine exhaust. The organic contamination levels do not seem to contribute to the discoloration of the various surfaces.

In spite of the significant amounts of terrestrial contaminants, adsorbed mainly from exposure during examination and exhibition, as well as from the bagging materials, it was still

possible to detect compounds derived from landing engine exhausts, and some compounds which may be spacecraft outgassing products. Unfortunately the LM exhaust products contaminated sample scheduled for collection by the Apollo 14 mission was not accomplished. It was accomplished by Apollo 15, and it will provide an unambiguous determination of the actual LM engine exhaust products found in the lunar environment. Such data will be of value in interpreting the findings of soft-landed spacecraft on other planets (for example, Viking on Mars). Furthermore, analyses for organic contaminants and identification of their sources, even if low in concentration, should be recognized as an important criterion for the design of optical or other active instruments for future spacecraft.

We thank Mrs E. Scott, Dr E. Gelpi and Miss P. Wszolek for technical assistance and Miss M. Petrie for high resolution mass spectrometry. This work was supported by the National Aeronautics and Space Administration.

BERND R. SIMONEIT
A. L. BURLINGAME

Space Sciences Laboratory, University of California, Berkeley, California 94720

Received September 7, 1971.

[1] Mission Evaluation Team, *Apollo 12 Mission Report*, MSC-01855, NASA-Manned Spacecraft Center, Houston, Texas (1970).
[2] Jaffe, L. D., and Rennilson, J. J., in *Surveyor Program Results*, NASA SP-184 (Washington DC, 1969).
[3] Simoneit, B. R., and Burlingame, A. L., in *Surveyor III Material Analysis Report*, NASA Special Publication (in the press).
[4] Burlingame, A. L., in *Advances in Mass Spectrometry* (edit. by Kendrick, E.), **4**, 15 (Institute of Petroleum, London, 1968).
[5] Burlingame, A. L., Smith, D. H., and Olsen, R. W., *Anal. Chem.*, **40**, 13 (1968).
[6] Burlingame, A. L., in *Recent Developments in Mass Spectroscopy* (edit. by Ogata, K., and Hayakawa, T.), 104 (University of Tokyo Press, 1970).
[7] Simoneit, B. R., Burlingame, A. L., Flory, D. A., and Smith, I. D., *Science*, **166**, 733 (1969).
[8] Flory, D. A., Simoneit, B. R., Burlingame, A. L., and Smith, I. D., *Experimental Determination of Potential Lunar Surface Organic Contamination in the Lunar Module Descent Engine Exhaust*, NASA Technical Report (in the press).
[9] Simoneit, B. R., and Flory, D. A., *Apollo 11, 12 and 13 Organic Contamination Monitoring History*, NASA Special Publication (in the press).

Printed in Great Britain by Flarepath Printers Limited, Watling Street, Colney Street, St. Albans, Herts.